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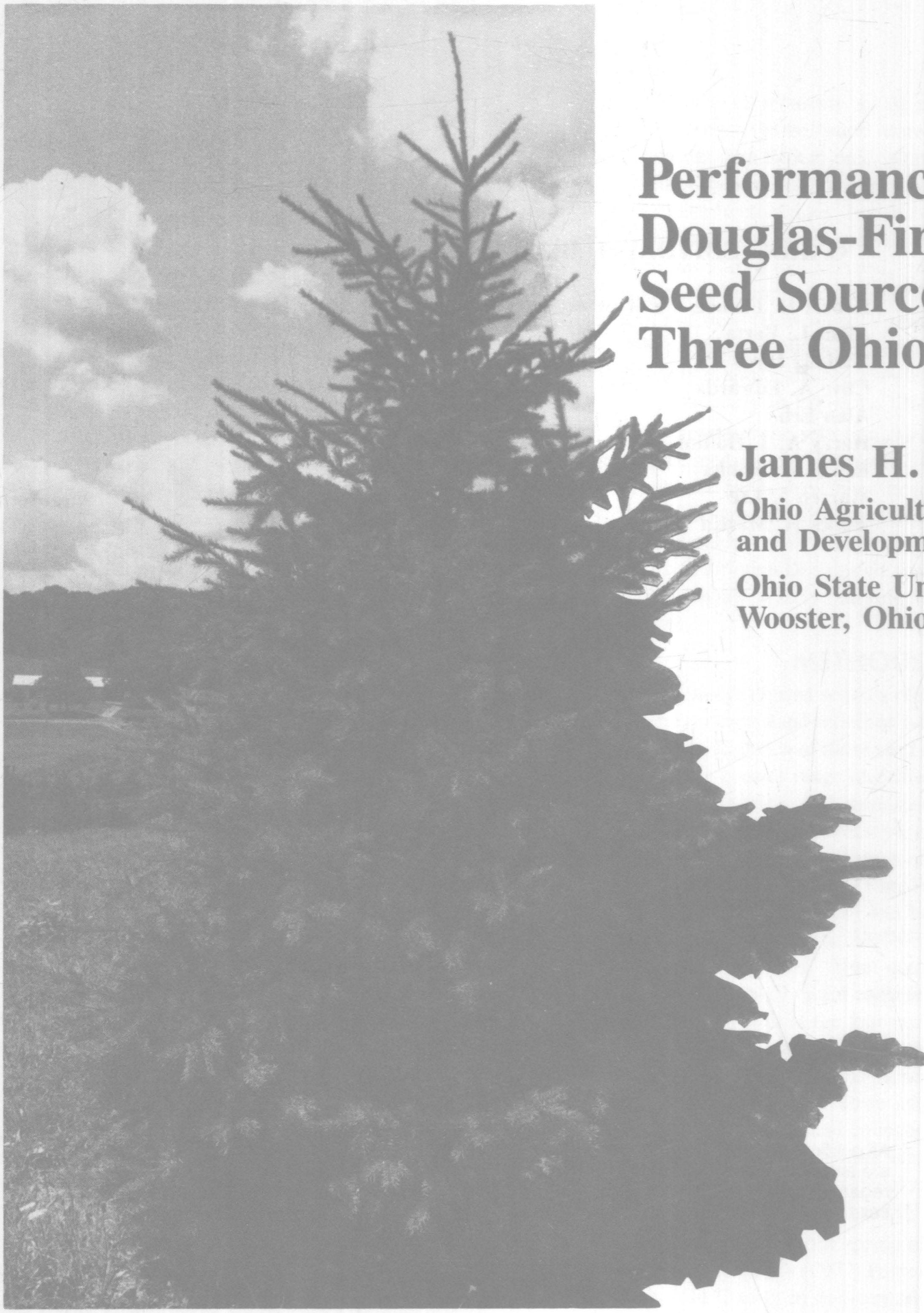

Performance of Douglas-Fir Seed Sources on Three Ohio Sites

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PERFORMANCE OF DOUGLAS-FIR SEED SOURCES ON THREE OHIO SITES

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INTRODUCTION

Douglas-fir *(Pseudotsuga menziesii)* is one of the most widely distributed conifers of western North America. Its natural range extends from approximately latitude 55°N in western Canada southward to northern Mexico and western Texas and from the Pacific Ocean eastward to the eastern slopes of the Rocky Mountains (Figure 1). There has been some confusion concerning taxonomic status of varieties of Douglas-fir. Some taxonomists have recognized three varieties, the Pacific Coast or "green" form *(P. menziesii* var. *virdis)*, the continental inland or "gray" form *(P. menziesii* var. *caesia)*, and the central and southern Rocky Mountain or "blue" form *(P. menziesii* var. *glauca)*. Others recognize only two varieties, the Pacific coastal form *(P. menziesii* var. *menziesii)* listed above and a "blue" form *(P. menziesii* var. *glauca)* which combines the range of the "blue" and "gray" varieties. For purposes of this paper, the latter two varietal designations will be used, with the coastal form occupying the range west of the Cascade Mountains and the blue form occupying the Inland Empire and Rocky Mountain areas east of the Cascades (Figure 1).

Studies have shown that most trees of the coastal form of Douglas-fir cannot withstand the harsh winter conditions of the north central and northeastern United States (Byrnes et al. 1958, Heit 1968, Van Haverbeke 1987, Wright et al. 1971). The blue form of the species is considerably slower growing than coastal form trees and there has been little or no interest in using Douglas-fir for wood production in the United States outside its natural range, though there has been in other parts of the world.

Douglas-fir has a number of characteristics which make it a desirable Christmas tree species. Needles are short (approximately ¾ to 1-½ inches), soft to the touch, and are retained well on cut trees. In addition, the basic conical shape of trees is good, and they can easily be sheared to produce high quality Christmas trees which bring premium prices on wholesale and retail markets.

Nationally, Douglas-fir annually ranks first or second, with Scotch pine *(Pinus sylvestris)*, in the number of Christmas trees harvested. However, most of those trees come from the West Coast. In Ohio, nearly 60 percent of trees harvested are Scotch pine, while Douglas-fir currently makes up only about two percent of the total harvest (Brown 1983).

There are a number of reasons why Douglas-firs are planted and harvested in relatively small numbers in Ohio. The species is known to be much more demanding in its site requirements than Scotch pine, white pine *(Pinus strobus)* and most of the spruces *(Picea* spp.), particularly in relation to soil moisture conditions. It is also very sensitive to competition from broadleaved grasses and herbs, and research in Ohio has shown that survival, growth and foliage characteristics can be improved on most sites by use of good weed control practices (Brown and Vimmerstedt 1976, Brown et al. 1988). Buds of Douglas-fir also tend to break dormancy prematurely in spring and new growth may be killed by spring frosts, particularly in low-lying "frost pockets."

Thus, improper site selection, along with use of trees of geographic seed sources which were slow growing or not frost and/or winter hardy, have been major factors affecting the success of Douglas-fir Christmas tree plantings in Ohio. The purpose of studies reported here was to investigate the performance of different Douglas-fir seed sources when planted on sites having widely varying internal soil drainage conditions.

METHODS

For this study, 19 seed sources of Douglas-fir were used, each representing a stand collection which included seed from several trees. Eighteen of those seed sources were from that portion of the species range identified as the Rocky Mountain or "blue" variety. The remaining source (No. 4 from the Snoqualmie National Forest) was of the Pacific coastal variety (Figure 1, Table 1). Sixteen of the seed sources were obtained from the Pennsylvania State University (PSU). Those seedlings (3-0 planting stock) had been grown at four different nurseries as part of the PENN-SYLVAN Christmas tree improvement programs. Tree quality (heights, caliper, root/shoot ratios, etc.) varied considerably, related in part to differences in growth at the four nurseries. However, there were no apparent relationships between quality of trees of individual seed sources and the nurseries in which they were raised. Seedlings (3-0) of three additional commercially-obtained sources (also stand collections) raised in the Ohio Department of Natural Resources Marietta Nursery were also included to provide broader regional representation of sources from areas not included in the PSU planting stock.

Trees were planted in the spring of 1973 on three sites at Ohio State University's (OSU) Pomerene Forest Laboratory in Coshocton County in east-central Ohio: six replications (19 seed sources each) were planted on a nearly level moist, well drained upland site having Gilpin silt loam soils (fine-loamy, mixed, mesic typic hapludult); three replications

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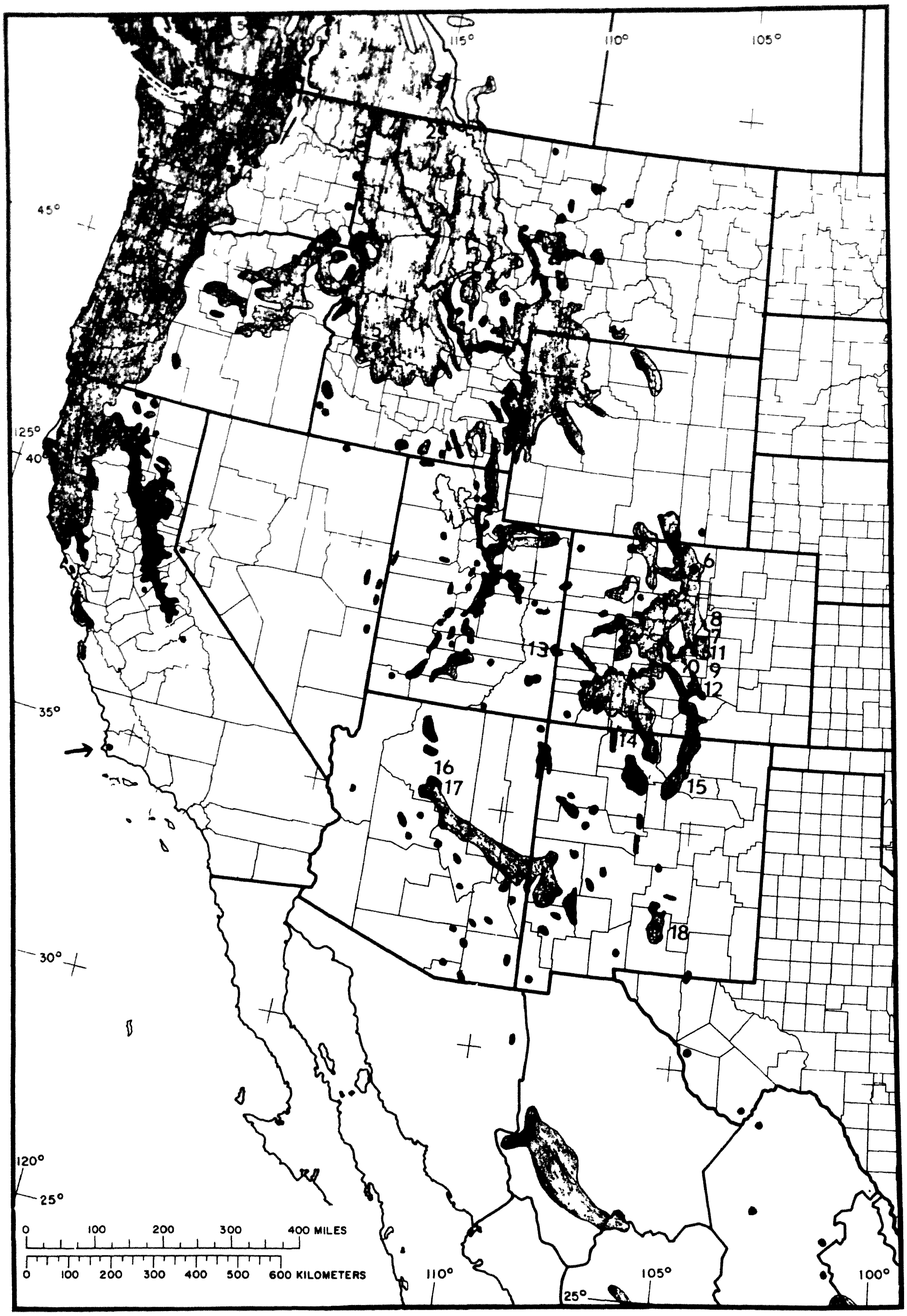

Figure 1. Natural range of Douglas-fir and locations of seed sources used in experimental plantings on three sites at Ohio State University's Pomerene Forest Laboratory. The dashed line in north central Washington represents the separation between the coastal form (var. *virdis*) and the Rocky Mountain (var. *glauca*) forms of the species.

Table 1. Origin of seed sources of Douglas-fir used in experimental plantings on three sites at Ohio State University's Pomerene Forest Laboratory.

Seed Source Code[1]	OARDC Acc. No.[2]	PSU Acc. No.[3]	State or Province	Lat. N	Long. W	Locale
1	29JB	——	British Columbia	51[4]	119[4]	Shuswap Lake[5]
2	100JB	——	Montana	49[4]	115[4]	Kootenai Nat. For.[5]
3	159JB	70HG69	Washington	48-12	117-23	Kaniksu Nat. For.
4	158JB	70HG11	Washington	47-13	121-07	Snoqualmie Nat. For.
5	28JB	——	Idaho	44[4]	116[4]	Boise Nat. For.[5]
6	156JB	67EP131-5	Colorado	40-28	105-26	Roosevelt Nat. For.
7	155JB	69EP329	Colorado	39-05	104-55	Pike Nat. For.
8	153JB	64EP5	Colorado	39-03	105-04	Pike Nat. For.
9	154JB	64EP3	Colorado	38-58	104-58	Pike Nat. For.
10	151JB	64EP1	Colorado	38-54	105-24	Pike Nat. For.
11	152JB	64EP4	Colorado	38-53	104-58	Pike Nat. For.
12	150JB	69EP339	Colorado	38-20	105-05	San Isabel Nat. For.
13	157JB	67EP176	Utah	38[4]	109[4]	Manti-La Sal Nat. For.
14	149JB	69EP349	Colorado	37-20	107-34	San Juan Nat. For.
15	146JB	67EP1	New Mexico	35-58	105-48	Santa Fe Nat. For.
16	148JB	69EP19	Arizona	35-21	111-57	Kaibab Nat. For.
17	147JB	69EP254	Arizona	35-19	111-24	Coconino Nat. For.
18	145JB	68EP59-69	New Mexico	32-57	105-43	Lincoln Nat. For.
19	160JB	D-o	Arizona-New Mex.	——	——	Selected Trees from Planted Stand of Arizona and New Mexico Source Trees.

[1]Seed source code number assigned for use in this study.
[2]Ohio Agricultural Research and Development Center (OSU) Seed Source Accession Number.
[3]Pennsylvania State University Seed Source Accession Number.
[4]Approximate Location
[5]Seed obtained from commercial seed dealer.

17 seed sources each) were planted on a gently sloping, dry, excessively well drained bottomland site with Chili gravelly loam soils (fine-loamy, mixed, mesic typic hapludalf); and three replications (19 seed sources each) were planted on a level, bottomland area having somewhat poorly drained Fitchville silt loam soils (fine-silty, mixed, mesic aeric ochraqualf). In each replication, trees were planted in four-tree lineal plots of each of the 17 to 19 seed sources, at a spacing of 8 feet between rows and 6 feet between trees in rows (seed source plots), using a randomized complete block experimental design. Vegetation within rows of trees was controlled in 3-foot wide bands for the first several years using herbicides and areas between rows were mowed two to four times each year until trees became too large for equipment to pass between them. Periodic evaluations and measurements included survival, heights, frost injury and winter damage, numbers of whorl limbs, trees with secondary (lammas) growth, forks in trees, needle lengths, needle retention and foliage color. Data were analyzed for each planting using least squares analyses of variance, with averages for the four-tree plots (or those surviving in plots) as data entries. Least Significant Differences at the 5 percent probability level (LSD.05) were computed for comparing differences between seed source means.

For purposes of data presentation, the seed sources of Douglas-fir used were assigned code numbers based on a north to south array of the origins of seed collections (Table 1).

RESULTS AND DISCUSSION

It was not possible to determine the extent to which planting stock quality, as influenced by the nursery in which seedlings were grown, may have influenced survival, growth and other characteristics of the Douglas-fir used in this study. However, weed control was excellent on all three sites during the early years of the study and effects of vegetative competition were minimal. As a result, irrespective of variations in planting stock quality, differences in performance of the Douglas-fir seed sources on the three sites having widely varying internal soil drainage characteristics reflect the sensitivity of trees to both "dry" and "wet" soil conditions.

Survival. Of the 19 seed sources used, trees of all but one were apparently adapted to climatic conditions at the east-central Ohio site where the study was conducted. The exception was Source 4 from the Snoqualmie National Forest in western Washington, the only one which represented the Pacific coastal form of the species range. When trees were received from Pennsylvania State University in the spring of 1973, foliage of seedlings of Source 4 showed definite symptoms of "winter-burn," although buds on trees were mostly alive. During the first growing season, those trees usually recovered and looked normal going into the first winter (1973-1974). However, trees showed considerable winter injury by the spring of 1974 and many were dead on each of the three sites. This pattern continued during each of the next two winters, and by the end of the third growing season (1975), all trees of Source 4 were dead (Table 2). A number of other studies have also found that trees of the coastal form cannot survive the cold winters that are characteristic of the north central and northeastern portions of the United States (Baldwin and Murphy 1956, Byrnes et al. 1958, Steiner and Wright 1975, Van Haverbeke 1987, Wright et al. 1971).

At the end of the first three years of the study, average survival of all trees was approximately 20 percent higher on the moist, upland site than on the dry and wet bottomland areas (Table 2.) At five years (1977), survival had declined to 68 percent on the moist site, 43 percent on the dry site, and only 26 percent on the wet areas. During succeeding five-year periods, overall survival of trees on the moist site declined slightly (to 62 percent after 15 years); while on the dry area it was only 36 percent after 15 years (Table 2). Although not shown in Table 2, survival of trees on the wet site was less than 20 percent by the end of the fifth growing season. Additionally, most trees in that planting were in very poor condition and the planting was removed in the winter of 1978-1979.

Although there were statistically significant differences in

Table 2. Periodic survival of Douglas-fir seed sources planted on three sites at Ohio State University's Pomerene Forest Laboratory.

Seed Source Code[1]	Locale	Survival, percent									
		"Moist" Site				"Dry" Site				"Wet" Site	
		1975	1977	1982	1987	1975	1977	1982	1987	1975	1977
1	Shuswap Lake	100	100	92	88	NP	NP	NP	NP	100	17
2	Kootenai Nat. For.	92	75	75	71	92	50	42	42	100	17
3	Kaniksu Nat. For.	54	46	38	38	33	17	17	17	33	0
4	Snoqualmie Nat. For.	0	0	0	0	0	0	0	0	0	0
5	Boise Nat. For.	100	88	83	83	NP	NP	NP	NP	83	17
6	Roosevelt Nat. For.	75	67	62	62	67	67	33	33	92	58
7	Pike Nat. For.	79	67	62	62	58	42	42	42	50	25
8	Pike Nat. For.	92	83	79	71	75	67	50	50	50	33
9	Pike Nat. For.	75	54	50	50	75	75	67	67	67	42
10	Pike Nat. For.	100	83	79	75	58	42	17	17	50	33
11	Pike Nat. For.	88	83	79	75	67	67	67	67	58	42
12	San Isabel Nat. For.	88	83	83	79	42	17	17	17	42	8
13	Manti-La Sal N. For.	50	33	25	25	42	33	33	33	33	0
14	San Juan Nat. For.	79	62	50	46	50	25	17	17	67	0
15	Santa Fe Nat. For.	83	71	71	67	83	42	25	25	83	58
16	Kaibab Nat. For.	92	79	79	79	50	33	33	33	58	33
17	Coconino Nat. For.	83	71	71	71	67	67	58	58	67	33
18	Lincoln Nat. For.	92	83	83	83	67	42	42	42	42	8
19	Ariz.-N.Mex.-Plant.	79	58	58	54	58	50	50	50	57	17
AVE.	———	79	68	64	62	58	43	36	34	60	26
	"F" VALUE	3.6[a]	2.6[a]	3.0[a]	2.9[a]	2.3[b]	2.3[b]	2.2[b]	2.2[b]	2.4[b]	2.2[b]
	LSD .05	21	27	29	28	27	27	28	29	28	30

[1]Seed source code number assigned for use in this study.
[a]Statistically significant at the 1 percent probability level.
[b]Statistically significant at the 5 percent probability level.

Figure 2. General view of planting of Douglas-fir seed sources on the upland, moist planting site at Ohio State University's Pomerene Forest Laboratory.

Figure 3. General view of planting of Douglas-fir seed sources on the dry, bottomland planting site at Ohio State University's Pomerene Forest Laboratory.

survival of trees of different Douglas-fir seed sources for each of the three evaluation periods and sites, there was no apparent relationship between area of origin and survival of individual seed sources, except for Source 4 from the Snoqualmie National Forest. On the moist site, two of the seed sources having the best survival were two northern origins from Shuswap Lake (No. 1) and Boise National Forest (No. 5) raised in Ohio from commercially obtained seed, while the fast-growing southern origin from Lincoln National Forest (No. 18) also had excellent survival at all measurement periods (Table 2). Similarly, origins having relatively low survival also came from throughout the north to south array of seed sources tested.

On the dry site, trees of two seed sources from the Pike National Forest (Nos. 8 and 10) had the best long-term survival, averaging 67 percent after 15 years. Conversely, some seed sources such as those from the Kootenai National Forest (No. 2) and Santa Fe National Forest (No. 15) that had very good third year survival declined markedly during succeeding years (Table 2). Again, sources with survivals both better and poorer than the plantation average came from throughout the north to south array of seed sources used.

On the somewhat poorly drained bottomland area several sources had excellent three-year survival (Table 2). However, mortality during the next two years was very high, and only two sources (No. 6, Roosevelt National Forest and No. 15, Santa Fe National Forest) had better than 50 percent survival at the end of five growing seasons.

Tree Heights. Growth of trees on the dry and wet sites was considerably slower than that on the moist, well drained upland area. Based on plantation means for each of the three study areas, trees on the moist site were more than 65 percent taller than those on the dry area at the end of each of the five-year measurement periods, while five years after planting, trees on the moist site were more than 75 percent taller than those on the wet site (Table 3, Figures 2 and 3). Large differences in height growth have also been noted in other Douglas-fir provenance studies in which trees were planted on more than one site (Byrnes et al. 1958, Wright etal. 1971).

As a group, trees of the Arizona and New Mexico seed sources (Nos. 15 to 19) were consistently among the fastest growing on both the moist and dry sites (Table 3). Other studies with Rocky Mountain forms of Douglas-fir have also shown that seed sources from those areas are usually among the fastest growing (Byrnes et al. 1958, Van Haverbeke 1987, Wright et al. 1971). On the moist site, the Shuswap Lake seed source (No. 2), the most northerly used in the study, also had above average growth, as did trees of two central Colorado provenances from the Pike National Forest. Growth of the eastern Washington seed source from the Kaniksu National Forest was also considerably above the plantation mean on the dry site; however only 17 percent of trees (2 of the 12 originally planted) were alive after 15 years (Tables 2 and 3).

Trees from the Manti-La Sal National Forest in Utah were particularly slow growing throughout the life of the study, averaging only 75 percent and 59 percent as tall as the plantation averages after 15 years on the moist and dry sites, respectively. Trees from the San Isabel National Forest (Colorado) were also very slow growing on the dry site (Table 3).

Evaluation of height growth data for trees on the wet site may not provide an accurate estimate of the real potential of different Douglas-fir seed sources. As noted previously, survival was very poor after five years in the field and only a few trees of each source were available for measurement.

Table 3. Periodic heights of Douglas-fir seed sources planted on three sites at Ohio State University's Pomerene Forest Laboratory.

Seed Source-		Moist Site						Dry Site						Wet Site	
		1977	-5yr.	1982	-10yr.	1987	-15yr.	1977	-5yr.	1982	-10yr	1987	-15yr	1977	-5yr
			%		%		%		%		%		%		%
Code[1]	Locale	Ht. ft.	Plan. Mean[2]	Ht. ft.	Plan. Mean[2]	Ht. ft.	Plan Mean[2]	Ht. ft.	Plan Mean[2]	Ht ft.	Plan Mean[2]	Ht ft	Plan Mean[2]	Ht ft	Plan Mean[2]
1	Shuswap Lake	2.5	109	8.0	102	18.6	108	NP	NP	NP	NP	NP	NP	0 7	54
2	Kootenai Nat. For.	1.9	83	7.1	91	16.0	93	1.3	87	4.6	97	9 8	96	1 1	85
3	Kaniksu Nat. For.	1.5	65	5.6	72	15.4	90	1.7	113	5 5	116	12 4	122	——	——
5	Boise Nat. For.	2.3	100	8.3	106	17.1	100	NP	NP	NP	NP	NP	NP	1 4	108
6	Roosevelt Nat. For.	1.9	83	7.5	96	16.4	96	1.1	73	3.9	82	9 1	89	0 8	62
7	Pike Nat. For.	2.4	104	8.2	105	18.6	110	1 4	93	4.6	97	10 2	100	1 2	92
8	Pike Nat. For.	2.0	87	6.5	83	15.0	87	1.3	87	4.8	102	10 6	104	1 4	108
9	Pike Nat. For.	2.4	104	8.4	108	17.7	103	1.4	93	5.3	112	9 9	97	1 3	100
10	Pike Nat. For.	2.5	109	8.1	104	15.8	92	1.6	107	5.0	105	11 2	111	1 3	100
11	Pike Nat. For.	2.1	91	6.2	79	14.8	86	1.5	100	3.8	80	9.0	88	1.4	108
12	San Isabel Nat. For.	2.1	91	7.0	90	15.0	87	1.0	67	2.6	55	6.0	59	1 5	115
13	Manti-La Sal Nat. For.	1.0	44	4.8	61	12.9	75	0.8	53	2.6	55	6.0	59	——	——
14	San Juan Nat. For.	2.7	117	8.7	112	18.1	105	1.0	67	3.3	70	8.5	83	——	——
15	Santa Fe Nat. For.	2.8	121	9.7	124	21.4	125	2.0	133	5.8	122	11.9	117	1 6	123
16	Kaibab Nat. For.	2.6	113	8.3	106	18.0	105	1.6	107	5.2	111	10.5	103	0.9	69
17	Coconino Nat. For.	2.7	117	8.6	110	17.8	104	2.1	140	6.5	138	12.5	123	1.8	139
18	Lincoln Nat. For.	2.9	126	9.6	123	20.2	118	2.2	147	6.5	137	12.7	125	1.2	92
19	Ariz.-N. Mex.-Planted	3.1	135	10.1	129	20.3	118	2.1	140	5.8	122	12.4	122	1.3	100
AVE.		2.3	100	7.8	100	17.2	100	1.5	100	4.7	100	10.2	100	1 3	100
"F" VALUE FOR SEED SOURCE		6.5[a]	——	5.5[a]	——	6.2[a]	——	3.8[a]	——	3.5[a]	——	3.8[a]	——	0.5	——
LSD.05		1.4	——	2.5	——	3.0	——	0.7	——	2.3	——	3.3	——	——	——

[1]Seed source code number assigned for use in this study.
[2]Seed source mean expressed as a percentage of the plantation mean.
[a]Statistically significant at the 1 percent probability level

The maximum height reached at five-years was only 1.8 feet and differences between seed sources were not statistically significant (Table 3).

Spring Frost and Winter Cold Injury. Spring frost injury is a major factor limiting the use of Douglas-fir for Christmas trees. Many trees tend to leaf out early in the spring and new foliage is readily killed by late frosts. Results of this study illustrate the importance of both seed source and topographic location of planting site on potential frost damage.

Spring frost injury to trees was evaluated in 1976 after a mid-May frost. As shown in Table 4, an average of 55 percent of trees on the moist, upland site had injury to buds and/or new foliage growth, while 84 percent of the trees on the dry bottomland and 73 percent on the wet area showed similar injury. Although differences between seed sources were not statistically significant, in part because of tree-to-tree variation within sources, there were large variations in average frost injury between seed sources in each plantation. On both the moist and wet sites, trees of the Shuswap Lake origin had the least frost injury; that source was not planted on the dry site. The Shuswap Lake area has been identified by seed collectors as a source that leafs out later in the spring and seedling nurseries offer it as a "frost-resistant" variety.

For the other seed sources used, there were no definite north to south trends in frost injury evident and results from the three plantings were also not consistent. On the moist, upland site three of the Pike National Forest provenances (7, 9, 11) showed relatively low incidence of damage, while trees of sources 10 (Pike National Forest) and 13 (Manti-La Sal National Forest) had low frost injury on the dry site. On the wet area, trees of Source 8 (Pike National Forest) and 12 (San Isabel National Forest) were the only other origins having less then 50 percent of trees injured by frost (Table 4). As a group, the Southern Colorado, Arizona and New Mexico origins showed intermediate to high frost injury on all sites.

Table 4. Spring frost and winter injury to Douglas-fir seed sources planted on three sites at Ohio State University's Pomerene Forest Laboratory.

		Spring Frost-1977 % Trees Injured			Cold Injury, Winter 1976-1977					
					Moist Site		Dry Site		Wet Site	
Seed Source Code[1]	Locale	Moist Site	Dry Site	Wet Site	% Inj.[2]	Sev. Rat.[3]	% Inj.[2]	Sev. Rat.[3]	% Inj.[2]	Sev. Rat.[3]
1	Shuswap Lake	29	NP	42	83	1.9	NP	NP	93	1.9
2	Kootenai Nat. For.	58	100	67	42	0.6	100	1.3	67	1.0
3	Kaniksu Nat. For.	73	92	60	77	1.1	99	1.2	—	—
5	Boise Nat. For.	57	NP	78	64	0.8	NP	NP	93	0.9
6	Roosevelt Nat. For.	41	83	92	12	0.5	83	1.7	100	1.8
7	Pike Nat. For.	28	72	100	17	0.3	100	1.2	100	1.8
8	Pike Nat. For.	47	100	36	21	0.7	78	1.3	94	1.8
9	Pike Nat. For.	38	100	83	42	0.6	100	1.3	100	1.6
10	Pike Nat. For.	59	33	83	49	0.5	22	0.5	100	1.2
11	Pike Nat. For.	43	83	100	17	0.2	89	1.2	94	1.3
12	San Isabel Nat. For.	71	100	44	39	0.8	100	2.7	93	2.5
13	Manti-La Sal Nat. For.	63	43	60	0	0.0	24	0.2	—	—
14	San Juan Nat. For.	60	100	89	63	1.9	100	2.9	—	—
15	Santa Fe Nat. For.	77	93	100	60	1.2	100	2.2	92	3.0
16	Kaibab Nat. For.	62	67	83	50	1.1	67	1.2	33	1.5
17	Coconino Nat. For.	68	67	100	72	1.6	67	2.3	94	2.5
18	Lincoln Nat. For.	53	93	83	95	1.3	100	2.5	95	2.2
19	Ariz.-N. Mex. Planted	61	100	58	84	1.4	100	2.2	67	2.3
AVE.		55	84	76	49	0.98	84	1.59	88	1.80
"F" VALUE FOR SEED SOURCE		1.5	1.2	1.6	5.7[a]	4.2[a]	2.3[a]	2.4[a]	0.4	1.0
LSD.05		—	—	—	31	0.81	47	1.23	—	—

[1]Seed source code number assigned for use in this study.
[2]Percent of total trees showing some injury from winter cold.
[3]Winter Injury Severity Rating: 0=None, 1=Slight, 2=Moderate, 3=Severe
[a]Statistically significant at the 1 percent probability level.

Other studies have also shown variable results and/or geographic trends in bud break and frost injury to Douglas-fir. Studies in Michigan (Wright et al. 1971) found that in one plantation, the Arizona-New Mexico provenances had the least frost injury in 1968 and next to the most in 1969. In another Michigan test (Steiner and Wright 1975), Arizona, New Mexico and southern Colorado origins were rated as highly susceptible to spring frost injury, northern Colorado sources as very highly susceptible, central Washington and Alberta as moderately susceptible and northern Rocky Mountain and Inland Empire sources as having low susceptibility. In Pennsylvania (Byrnes et al. 1958), trees of Pacific coastal forms of Douglas-fir were generally least damaged by frost, northern Rocky Mountain sources were intermediate, and central and southern Rocky Mountain origins were most severely injured.

Winter Cold Injury. Cold injury to trees was evaluated in late March of 1977, following the severe, extremely cold winter of 1976-1977 which occurred in Ohio and much of the northern United States. As discussed previously, all trees of the one coastal provenance of Douglas-fir used in the study (No. 4 from the Snoqualmie National Forest in western Washington) had died from cold injury prior to that time.

In rating winter injury to trees of the remaining 18 seed sources, two criteria were used: (1) percentage of trees showing any visual winter injury was determined; and (2) severity of injury was rated using a 4-point scale, with 0=none, 1=slight, 2=moderate, and 3=severe. In all cases, injury was confined to "winter-burn" or drying of foliage; no death of buds or die-back of stems was noted.

Average winter injury to trees, in terms of both percentage of trees showing damage and the severity of injury, was considerably lower on the upland, moist site than on the dry and wet bottomland areas (Table 4). Similarly, injury to individual provenances was consistently lower on trees on the upland site.

With the exception of the provenance from the Kaibab National Forest (No. 16), trees of the southern Colorado, Arizona and New Mexico origins showed the most winter injury, averaging slight to moderate on the moist site and moderate to severe on the two bottomland areas (Table 4). On the moist site, the Shuswap Lake source also showed relatively high injury. With the exception of that provenance, trees of the central and northern Rocky Mountain origins showed less severe injury, although high percentages of trees had at least some visual damage. Trees of the Manti-La Sal National Forest provenance were the most winter hardy of all those tested, with none of the trees showing injury on the upland area and only 24 percent of trees having very slight discoloration on the dry site (Table 4).

These results generally parallel those found in other studies in Michigan (Wright et al. 1971) and Nebraska (Van Haverbeke 1987) but in Pennsylvania (Byrnes et al. 1958), sources from the southern Rocky Mountains were rated to be more winter hardy than those from further north, but the latter study did not include sources from southern Colorado, Arizona or New Mexico.

Foliage Color. Foliage color was evaluated in October 1977 using a three point scale, with 1=blue-green, 2=green and 3=yellow-green. For the moist, upland and dry, bottomland sites, "average" color for trees of all Douglas-fir provenances was essentially the same, averaging 1.65 and 1.64 (blue-green to green), respectively, for the two areas. Differences between sites for individual seed sources were also relatively small. On the wet site, color was somewhat poorer, averaging 1.97 ("green").

For the moist site, there were statistically significant differences between provenances in foliage color. As a group, trees of the more southerly origins (southern Colorado, Arizona and New Mexico) tended to be more blue-green in color, while those from the central and northern Rocky Mountains tended to be at or near the green rating (Table 5). On the wet area, color ratings were skewed toward the green rating for the southern sources and toward yellow-green for the northern ones (Table 5).

Results of other studies show trends similar to those reported here. In nursery and field planting evaluations in Michigan (Wright et al. 1971), trees from Arizona, New Mexico and southern Colorado were characterized as having the "bluest" color, those from northern Colorado were rated from "intermediate blue-green" to "light green," and those from further north were characterized as "dark green." Results were similar in evaluations of nursery seedlings in New York (Heit 1968). In Pennsylvania (Byrnes et al. 1958), trees of southern Rocky Mountain seed sources were rated as being "blue-green" to "gray-green", those from the central range as "green" to "gray-green" and trees from the northern Rocky Mountains and Inland Empire areas as being "gray-green."

Needle Lengths. Needle lengths (rated in October 1977) of individual seed sources of Douglas-fir varied considerably, and differences between seed sources for trees growing on the upland site were statistically significant (Table 5). However, there were no identifiable geographic trends in any of the three plantations. It is interesting to note, however, that site quality had a pronounced effect on average needle lengths: on the upland, moist site, needles averaged 27 mm in length, 35 percent greater than the average for dry-site trees and nearly 60 percent longer than those of trees on the wet site (Table 5).

No data are available from other studies to compare with variations in needle lenghts reported here.

Needle Retention. Appearance or "density" of a tree can be affected appreciably by both the amount of foliage and number of years it is retained on stems. In this study, needle retention was evaluated in October 1977. Differences between seed sources were significant for both the moist and dry planting sites (Table 5). However, as with needle lengths,

Table 5. Foliage color, needle lengths and needle retention on Douglas-fir seed sources planted on three sites at Ohio State University's Pomerene Forest Laboratory.

Seed Source Code[1]	Locale	Foliage Color[2] Moist Site	Dry Site	Wet Site	Needle Length-mm Moist Site	Dry Site	Wet Site	Needle Ret.-yrs. Moist Site	Dry Site	Wet. Site
1	Shuswap Lake	1.8	NP	1.7	30	NP	18	2.0	NP	1.0
2	Kootenai Nat. For.	1.7	1.7	2.5	27	18	18	2.5	1.7	1.7
3	Kaniksu Nat. For.	1.7	1.7	——	19	24	——	2.2	0.9	——
5	Boise Nat. For.	2.0	NP	2.3	24	NP	16	1.8	NP	1.0
6	Roosevelt Nat. For.	2.0	1.8	2.2	23	14	13	2.3	2.0	1.3
7	Pike Nat. For.	2.0	1.8	2.3	33	20	15	2.7	2.0	1.5
8	Pike Nat. For.	2.1	2.0	2.5	32	21	20	1.8	1.7	1.5
9	Pike Nat. For.	1.8	1.7	2.5	28	18	13	2.9	2.0	1.0
10	Pike Nat. For.	1.8	1.7	1.7	26	16	17	2.5	2.0	1.7
11	Pike Nat. For.	1.8	1.8	2.0	25	20	18	2.0	2.0	2.0
12	San Isabel Nat. For.	1.8	1.7	1.5	25	20	14	2.2	1.9	2.0
13	Manti-La Sal Nat. For.	1.8	1.5	——	19	16	——	2.8	2.9	——
14	San Juan Nat. For.	1.4	1.5	——	26	16	——	2.4	1.1	——
15	Santa Fe Nat. For.	1.4	1.5	1.7	29	22	20	2.3	2.0	1.3
16	Kaibab Nat. For.	1.2	1.5	1.5	25	23	11	2.5	2.1	1.0
17	Coconino Nat. For.	1.4	1.5	1.7	33	23	26	2.3	2.3	1.5
18	Lincoln Nat. For.	1.1	1.4	1.8	27	26	14	2.3	1.9	1.1
19	Ariz.-N. Mex. Planted	1.3	1.5	1.7	23	21	19	2.6	1.7	1.0
AVE.	. .	1.64	1.65	1.97	27	20	17	2.3	1.9	1.4
"F" VALUE FOR SEED SOURCE		3.25[a]	0.54	.56	3.7[a]	1.3	0.5	2.74[a]	2.53[b]	0.54
LSD .05		0.44	——	——	5.5	——	——	0.57	0.64	——

[1]Seed source code number assigned for use in this study.
[2]Foliage color rating: 1=blue-green, 2=green, 3=yellow-green.
[a]Statistically significant at the 1 percent probability level.
[b]Statistically significant at the 5 percent probability level.

no geographic trends were apparent. Trees of the more southerly seed sources generally had average needle retention scores which were at or above the plantation means. However, provenances from central and northern Rocky Mountain areas were both variable (Table 5).

There were definite effects of site quality on needle retention on trees. On the moist, upland site, needle retention averaged 2.3 years, 21 percent longer than the dry site average (1.9 years) and 64 percent longer than that of the wet bottomland area (Table 5).

Again, no comparative data are available from other Douglas-fir seed source studies.

Limbs on Terminal Shoots. Unlike the pines which normally do not have internodal buds and lateral limbs on unsheared trees, Douglas-fir and other single-needled conifers usually have buds between the major whorls which grow into internodal branches. On Christmas trees and ornamentals, those branches serve to cover the main stem of the tree and increase crown density.

In October 1978, counts were made of the number of internodal twigs that occurred on the main terminal shoot (1978 growth) of each tree on the moist and dry planting sites. Counts were not made on the wet area because of the very low survival and overall poor condition of remaining trees.

As shown in Table 6, there were statistically significant differences in numbers of lateral twigs or branches on trees of the different seed sources. These ranged from 4.0 (Source 13, Manti-La Sal National Forest) to 11.1 (Source 19, planted Arizona-New Mexico trees) on the upland site and from 1.0 (Source 13) to 8.5 (Source 18, Lincoln National Forest) on the dry site. On the upland site there were no obvious relationships to geographic location; on the dry area, however, southern origins generally had higher numbers of internodal twigs (Table 6). As observed in a number of other characteristics, average numbers of twigs for all sources and for individual seed sources were generally considerably higher on moist-site trees.

Secondary Growth. In some years and for some species and/or seed sources, trees may go through a major shoot growth phase, set terminal buds and then, after a short resting

Table 6. Limbs on terminal shoots, trees with secondary growth and percent forked trees for Douglas-fir seed sources planted on three sites at Ohio State University's Pomerene Forest Laboratory.

Seed Source Code[1]	Locale	No. Limbs on Terminal Shoot Moist Site	Dry Site	% Trees with 2nd Growth Moist Site	Dry Site	%Forked Trees Moist Site	Dry Site
1	Shuswap Lake	6.8	NP	14	NP	75	NP
2	Kootenai Nat. For.	9.0	3.3	16	10	61	89
3	Kaniksu Nat. For.	6.5	4.5	0	2	53	50
5	Boise Nat. For.	5.0	NP	22	NP	70	NP
6	Roosevelt Nat. For.	6.1	1.7	2	0	68	83
7	Pike Nat. For.	10.5	4.0	24	17	61	83
8	Pike Nat. For.	5.3	2.3	28	19	65	100
9	Pike Nat. For.	7.8	3.0	11	17	56	89
10	Pike Nat. For.	6.5	3.0	21	17	64	100
11	Pike Nat. For.	7.3	4.3	15	17	80	100
12	San Isabel Nat. For.	5.5	2.2	17	0	89	100
13	Manti-La Sal Nat. For.	4.0	1.0	18	7	62	37
14	San Juan Nat. For.	5.7	2.1	52	50	70	63
15	Santa Fe Nat. For.	6.8	5.5	66	52	78	75
16	Kaibab Nat. For.	7.2	5.3	36	33	67	83
17	Coconino Nat. For.	6.3	4.0	47	55	92	100
18	Lincoln Nat. For.	8.2	8.5	80	52	67	50
19	Ariz.-N. Mex. Planted	11.1	7.7	64	37	66	83
AVE.	——	7.0	3.9	30	24	69	80
"F" VALUE FOR SEED SOURCE		1.92[b]	4.74[a]	4.6[a]	0.8	0.9	0.8
LSD.05		3.41	3.02	30.5	——	——	——

[1]Seed source code number assigned for use in this study.
[a]Statistically significant at the 1 percent probability level.
[b]Statistically significant at the 5 percent probability level.

period, resume shoot growth. This later additional growth is commonly referred to as "secondary" or "lammas" growth and most typically occurs on the main leader of trees. The occurrence of secondary growth on trees is related to favorable late growing season conditions, particularly favorable moisture. Such growth can be a problem on Christmas trees; if it occurs after trees are sheared or after small trees are inspected for shearing, the additional growth may leave long internodes which result in "holes" or variations in tree density. Depending on the nature of the growth, it can also result in double stems on trees (Brown 1981).

In October 1980, trees were rated for the numbers (percent) having secondary growth on the terminal shoot. Differences were statistically significant among seed sources on the moist, upland area, and on both the moist and dry areas, two groups were readily identifiable. On both sites, trees of origins from southern Colorado, Arizona and New Mexico (with the exception of Source 16 from the Kaibab National Forest) had much higher percentages of trees with secondary growth (Table 6). Averages for the two planting sites also showed that numbers of trees having secondary growth were consistently higher on the moist than on the dry site for most seed sources.

No comparable data was available from other Douglas-fir seed source studies. However, research with some other species, including Scotch pine (Wright and Bull 1963) and white pine (Garrett et al. 1973, Genys 1968), has shown that southern origins often have higher incidences of secondary growth.

Forked Trees. Forks in trees can result from a number of factors, including physical damage, frost damage or winter kill to buds and shoots, secondary growth, etc. In October 1980, all trees on the moist and dry sites were scored for presence or absence of at least one fork in the main stem. As shown in Table 6, a high percentage of total trees, 69 percent on the moist site and 80 percent on the dry one, had forked trees. Within sites, individual seed sources varied from 53 to 92 percent with forked trees on the moist site and from 37 to 100 percent on the dry site, with no statistical differences between seed sources.

Forks on individual trees may have occurred over a period of years and from one or more causes. No close correlations were found between forking and secondary growth on either the moist (R=0.37) or dry site (R=0.08). Similarly, correlations were not significant between forking and frost damage in 1977 (R=0.24 and 0.07 for the moist and dry sites respectively) or forking and severity of winter injury (R=0.13 and 0.08 for the moist and dry sites). Examination of the data and other observations made during the study indicated that frost injury, which occurred in several years and not just 1977, was a likely cause of much of the forking. As noted in previous discussions, the winter injury was confined to foliage damage and buds and stems were not killed. In the case of secondary growth, it was noted that a much higher percentage of southern source trees had secondary growth, while forking was well distributed through all of the provenances. It was also noted that both frost injury and forking were higher on the bottomland, dry area than on the upland, moist site where air drainage was better.

CONCLUSIONS AND RECOMMENDATIONS

Results of this study emphasize the importance of several factors which can influence the success of Douglas-fir Christmas tree and ornamental plantings in Ohio and similar environments in the north central and northeastern United States.

The critical influence of site quality, notably soil moisture conditions, was evident for all traits considered in this study. On the dry site, neither average survival (36 percent) nor total tree heights (4.7 feet) on unsheared trees at 10 years (Tables 2 and 3) would have been adequate to permit profitable Christmas tree operations. In addition, foliage quality of trees on the dry site was generally much poorer. Results on the wet planting site were even poorer, with survival, growth and foliage characteristics being so poor that the planting was eliminated from the study after six growing seasons.

Based on results of this study, and others in the Ohio Agricultural Research and Development Center (OARDC) Christmas tree research program, it is recommended that Douglas-fir Christmas tree plantings be confined to well drained planting sites within the relatively narrow range from moist to "moderately" dry, whether determined by soil texture and water table characteristics or as influenced by topographic factors. Results of research studies and experiences of growers indicate that soils showing any indication of restricted soil drainage characterics—poorly, somewhat poorly and even moderately well drained—should be avoided. In research plantings at the OARDC, mortality of Douglas-fir has occurred even after particularly wet years well into the Christmas tree rotation on marginal, well to moderately well drained soils after considerable investments in time and money have been made.

Determining the transition from moist to moderately dry to dry on planting sites may be difficult. For that purpose, planting guides such as those presented in the "Ohio Christmas Tree Producers Manual" (Brown et al. 1981) should be helpful. In general, coarse textured, sandy soils and shallow soils should be avoided for Douglas-fir plantings. In more hilly terrain, such as southeastern Ohio, ridgetop positions and south and west facing areas, particularly on upper slopes, are also questionable planting sites and probably should be avoided. On north and east facing slopes, available soil moisture will generally be higher.

The higher incidence of frost damage to trees on the two bottomland sites also points out the importance of selecting upland sites having good cold air drainage for Douglas-fir plantings, where possible. Results in OARDC research plantings show that Douglas-fir planted on a bottomland site having suitable moisture characteristics can develop into marketable Christmas trees, but that higher incidences of frost injury may increase rotation length and reduce tree quality somewhat.

Results of this and other studies illustrate the importance of seed source of planting stock to the success of Douglas-fir plantings. Several sources had total heights in excess of 8 feet at 10 years (Table 3). However, when other characteristics such as foliage color are considered, origins from the southern part of the range in southern Colorado, Arizona and New Mexico provide the best combinations of characteristics. Adequate growth rate and frost resistance was also observed for the Shuswap Lake seed source. Commercial seedling nurseries commonly offer many of these planting stock choices, including seed sources from the Lincoln and Santa Fe National Forests in New Mexico, the Apache and Coconino National Forests in Arizona, the San Isabel, San Juan and Rio Grande in southern Colorado, and Shuswap Lake, British Columbia.

Proper selection of cultural practices is another area where growers can exercise strong influence on the success of Douglas-fir Christmas tree plantings. As noted previously, the planting stock used in this study was variable and use of larger, better balanced planting stock, including transplants rather than seedlings, should give better survival and shorter rotation lengths. Good weed control is also essential to improve survival, growth and foliage characteristics (Brown and Vimmerstedt 1976, Brown et al. 1988). Research at the OARDC has also shown that on certain planting sites, Douglas-fir can benefit from fertilization, particularly with nitrogen (Brown and Vimmerstedt 1976, 1981).

With all of the potential limitations to planting and managing Douglas-fir Christmas trees, the question of whether growers should consider the species for planting arises. The major reasons why Douglas-fir has a continuing potential for planting in Ohio and other north central and northeastern parts of the U.S. are value and quality Wholesale and retail prices for Douglas-fir Christmas trees are normally 50 to 100 percent higher than for the pines; additionally, in competitive markets, sales of the species continue to be strong, even at higher prices. Thus, with proper consideration of appropriate geographic origin of planting stock, site selection, and cultural management, the species represents a real potential for high value commercial production.

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LITERATURE CITED

Baldwin, H. I. and D. Murphy. 1956. Rocky Mountain Douglas-fir succeeds in New Hampshire. Fox For. Note 67.

Brown, J. H. 1981. How shearing affects Christmas tree quality. Ohio Report 66: 37-40.

Brown, J.H. 1983. Trends in Christmas tree production and marketing. Ohio Report 68: 3-6.

Brown, J. H., W. F. Cowen, Jr. and R. B. Heiligmann. 1981. Ohio Christmas Tree Producers manual. OSU Coop. Ext. Serv. Bull. 670.

Brown, J. H., M. A. Spetich and R. B. Heiligmann. 1988. Effects of frequency of chemical weed control on growth and quality of Christmas trees. In press.

Brown, J. H. and J. P. Vimmerstedt. 1976. Site evaluation, weed control and fertilization: three factors affecting Christmas tree planting success. Penn. Christmas Tree Bull. 133: 7-9.

Brown, J. H. and J. P. Vimmerstedt. 1981. Fertilization of established Douglas-fir Christmas tree plantations. Ohio Agric. Res. and Dev. Center Res. Bull. 1154.

Byrnes, W. R., H. D. Gerhold and W. C. Bramble. 1958. Douglas-fir varietal tests for Christmas trees in Pennsylvania. Penn. Agric. Exp. Sta. Prog. Rept. 198.

Garrett, P. W., E. J. Schreiner and H. Kettlewood. 1973. Geographic variation of eastern white pine in the northeast. U.S.D.A. For. Serv. Res. Pap. NE-274.

Genys, J. B. 1968. Geographic variation in eastern white pine, two-year results of testing range-wide collections in Maryland. Silvae Genetica 17: 6-12.

Heit, C. E. 1968. Propagation from seeds. Part 17: testing and growing Douglas-fir seeds from different sources. American Nurseryman.

Steiner, K. C. and J. W. Wright. 1975. Douglas-fir Christmas trees: variation in frost susceptibility and time of leafing out in Michigan. Mich. Academician 7(2): 185-190.

Van Haverbeke, D. F. 1987. Genetic variation in Douglas-fir: a 20-year test of provenances in eastern Nebraska. U.S.D.A. For. Serv. Gen. Tech. Rept. RM-141.

Wright, J. W. and W. I. Bull. 1963. Geographic variation in Scotch pine. Results of a 3-year Michigan study. Silvae Genetica 17: 6-12.

Wright, J. W., F. H. Kung, R. A. Read, W. A. Lemmien and J. W. Bright. 1971. Genetic variation in Rocky Mountain Douglas-fir. Silvae Genetica 20: 54-60.

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